D. SAFETY ASSESSMENT

1. Policies and Procedures

a. Range Safety Responsibility - The overall responsibility for safety at the GSFC/WFF is vested in the Director, GSFC. In turn, this overall responsibility is delegated to the Director of the Suborbital Projects and Operations Directorate (SPOD) at the WFF. Within SPOD, the Safety and Quality Assurance Engineering Branch is charged with implementing range safety.[18]

(1) The Head, Safety and Quality Assurance Engineering Branch is responsible for:

(a) Program safety management for WFF programs and launch range activities conducted from Wallops Island.

(b) Reviewing and establishing procedures that assure each project or launch is performed in accordance with established safety policies and criteria.

(c) Approval of any deviation from the requirements set forth in the safety plans.

(d) Assuring that a Ground Safety Plan and a Flight Safety Plan are prepared by the Ground and Flight Safety Section prior to any launch operation. The Ground Safety Plan covers operating variables involving the storage and handling of explosives and propellants, vehicle assembly and pad preparations where other than normal procedures are used. The Flight Safety Plan covers the quantitative and qualitative aspects of the proposed vehicle flight.[19]

(2) The Head, Launch Vehicles Branch, is responsible for:

(a) Exercising control over the operation of the Branch to assure maximum safety and to minimize the taking of unnecessary risks during the preparation of vehicles for launching, and to resolve any conflict between safety criteria and operational exigencies. He appoints a Pad Supervisor who is responsible for coordinating and implementing safety procedures for each operation, and who is responsible for all safety matters within the launch areas.

(b) Referring all unapproved program procedures or activities requiring safety review to the Ground and Flight Safety Section.

(c) Assuring that all power systems and User supplied equipment is inspected before use.

(d) Assuring proper storage and use of all radioactive sources and maintaining records and other documentation.

(e) Providing written authorization for handling and transporting liquid propellants, allowing personnel to take spark-producing devices into explosives handling areas, and for doing repair work on magazines containing explosives or other hazardous materials.

(f) Maintaining solid propellant storage magazines and shipping, receiving and transporting ordnance at WFF.

(g) Maintaining facilities for, and performing, ordnance preinstallation testing.

(3) The Head, Ground and Flight Safety Section, is responsible for:

(a) Establishing ground and flight safety plans which provide the specific safety criteria and procedures to be observed for each launch vehicle and payload.

(b) Providing an engineering evaluation of all vehicles and payloads to assure they meet the ground and flight safety policies, and to categorize ordnance devices.

(c) Developing Safety Analysis Reports for the approval of the Director of Suborbital Projects and Operations for systems which exceed established risk criteria.

(d) Acting as Range Safety Officer for all flights being launched from WFF and any special mobile expeditions as required.[19]

(4) The Test Director is responsible for:

(a) Exercising operational control and coordination of all countdown operations.

(b) Controlling activities in the immediate vicinity of the launch area to prevent unauthorized vehicular and pedestrian traffic, and calling a hold in the countdown when, in the opinion of the Pad Supervisor, such action is necessary in the interest of safety.

(c) Ensuring that the Pad Supervisor is present in the launch area before any operation commences that will create a hazardous condition, or before any such operation that has been interrupted is resumed.

(d) Assuring that all flight safety conditions are in accordance with the Flight Safety Plan prior to launch; i.e., launcher settings, wind limitations, support aircraft, predicted flight course and range clearance areas.

b. Flight Termination System Requirements - A command/destruct capability, which meets Range Safety requirements, is required on vehicles with guidance systems that provide the capability to violate the flight safety limits. GSFC/WFF flight safety policy requires a flight termination system in every stage of a launch vehicle unless it is shown that the flight is inherently safe, which is determined by probability estimates based on known system errors and the following set of qualifying conditions:

(1) The launch vehicle does not contain a control or guidance system and is incapable of assuming any trim angle that produces sufficient lift for the vehicle to violate the planned impact area.

(2) The launch vehicle control system does not have sufficient turning capability to violate the planned impact area.

(3) The acceleration at lift-off must be greater than 3.5 g's and/or there must be a high degree of confidence that the vehicle can be wind-corrected accurately.

(4) For new or modified vehicles, the proposed launch elevation angle does notexceed 80^0, and the proposed azimuth is such that the geographical advantages of impact areas are recognized. If the vehicle

reliability has been established, the 80^0 launch elevation angle limit may be exceeded, provided that the probability of failure does not violate flight safety limits and the impact criteria are not violated.

If a launch vehicle cannot meet the above set of conditions, a flight termination system must be employed. The WFF requirement for the flight termination systems is for a reliability of 0.999 at the 95% confidence level. FTS's flown at the WFF are subjected to rigid design review, test and quality assurance standards.

c. Safety Waivers - Range Users must submit requests for any waivers from the prescribed procedures before arriving at the GSFC/WFF. Waiver approval authority is the Director of Suborbital Projects and Operations.

2. Safety Organization - The Safety and Quality Assurance Engineering Branch of the Engineering Division plans, develops and provides functional management of Wallops Flight Facility policies and procedures for program safety. Although the Engineering Division is in the chain of command between the Branch and the Director of Suborbital Projects and Operations, the Safety and Quality Assurance Engineering Branch has direct access to the Director for program safety. This Branch is responsible for initiation of development of new methods, techniques, procedures and/or systems to reduce hazards and improve operating techniques. The WFF RSO works for this organization and is responsible for:

- Assuring that launch safety criteria are met
- Controlling and operating the real time flight termination system
- Establishing requirements of real time data and display system
- Acting as advisor for international programs and training

In addition, the Ground and Flight Safety Section of this Branch is responsible for determining flight safety limits, defining launch limitations and performing risk assessment analyses. See **Figure 14**$_3$ for a block diagram of the WFF Safety organization.

3. Safety Personnel Training - The WFF has established a formal and comprehensive Range Safety Officer training program. Training of RSO's is the responsibility of the WFF Safety and Quality Assurance Branch. Training of other safety personnel who support the RSO during pre-launch preparations, countdown and vehicle flight is also conducted. The following information is provided to outline the steps and procedures involved with training these personnel at the WFF. The training procedures for Range Safety Officers are presented first:

a. Background Requirements - The desired background requirements for a potential Range Safety Officer are:

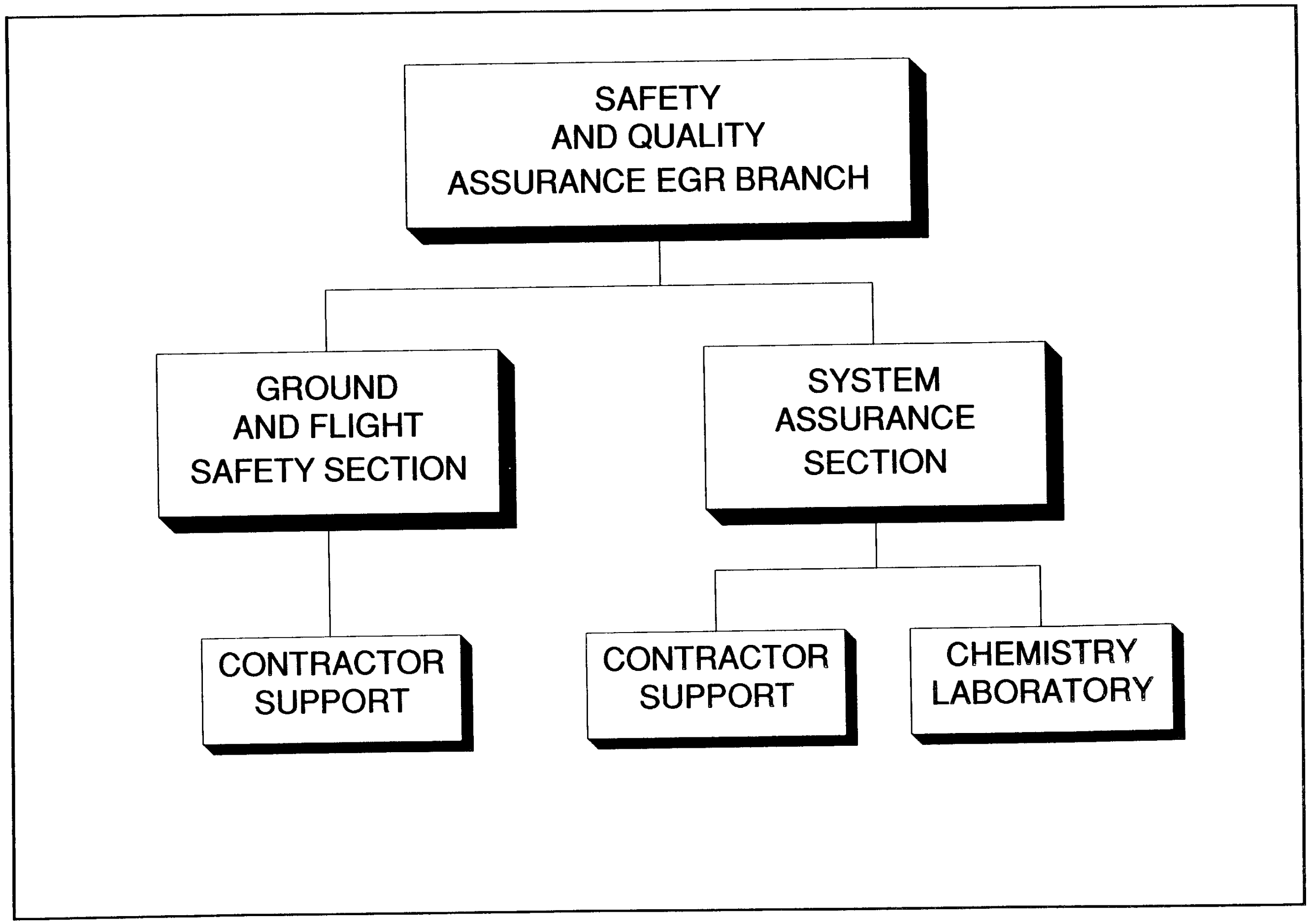


FIGURE 14. WALLOPS FLIGHT FACILITY SAFETY ORGANIZATION

(1) Grade - Must be a U.S. Government employed civilian, GS-09 or above. The grade level required varies, dependent on the complexity of the launch operation. Currently only GS-12 and above civilians are selected to serve as RSO's for orbital missions.

(2) Education - Should have a Bachelor's degree, preferably a master's, in some field of engineering or possess equivalent technical experience. The candidate should understand the application of typical range instrumentation systems, and the behavior of ballistic and aerodynamic vehicles in flight under external forces.

(3) Experience - Should have a background in missile, space or aircraft operations requiring real-time decision making.

b. Training Plans/Certification - Training programs have been developed to assure that candidate RSO's are properly trained and to serve as a documented record of the trainee's progress and performance. An outline of the WFF RSO training program is shown in the following paragraphs:

(1) Wallops Philosophy - The trainee is expected to review and understand the "Range Safety Policies and Procedures" document, probabilistic theory, land, ship and aircraft criteria, casualty expectation criteria, overflight issues and political ramifications involved in mission operations.

(2) Impacts - The trainee must understand the nature of impacting spent stages and debris from a destructed vehicle as it relates to clearing hazardous areas, providing surveillance, defining buffer zones, dispersion characteristics, probability and impact calculations for land, ship and aircraft and casualty expectation calculations.

(3) Overflights - The trainee is expected to become well versed in the area of overflight hazards and risks. This includes the understanding of the principles of land impact probability calculations, casualty expectation calculations, defining acceptable launch corridors and vehicle flight limits such as azimuth/elevation and Instantaneous Impact Prediction (IIP).

(4) Guidance Systems - The trainee is instructed on the types of guidance systems used on the vehicles flown from the WFF. These include the ballistic missiles which have no active guidance system, programmed guidance and seeker guidance.

(5) Flight Safety Limits - The trainee must understand the safety limits as they relate to azimuth and elevation considerations. Azimuth issues such as nominal azimuth to land mass, data source "error", Coriolis effect, turning rates (vehicles with guidance and destruct systems), dispersion (vehicles without a destruct system) and buffer zones. Elevation issues include the pitch program, stage impacts, maximum range considerations and stage burnout considerations.

(6) Hazard Areas - The trainee is expected to understand the definitions of hazard areas used at the WFF, the clearance procedures for the defined hazard areas, the components that make up the hazard areas such as the flight control corridors, data source "error", turn rates

versus reaction time, debris drag impact and buffer zones.
(7) Missile Exercises - The trainee is instructed in the use of missile hazard areas, vehicle destruct lines, aircraft vectoring and missile fire envelopes.
(8) Computer programs - The trainee must understand the various Range Safety computer programs use at the WFF. These include the Nemar 6-D (nominal trajectory, turn rates and drag impacts), Oblate (latitude, longitude, azimuth and range), Time Track ("vacuum" impacts), Map (IIP map and destruct lines), IIP (real-time), SENS-5D (trajectory, wind weighting), ship and aircraft impact probability, casualty expectation and statistical dispersion.
(9) Flight Safety - The trainee is expected to calculate flight safety limits for a given vehicle, have a thorough knowledge and understanding of the use of the real-time IIP information and must understand the issues involved with orbital predictions as they relate to a particular vehicle.
(10) Weather - The trainee must understand the weather constraints and issues involved as they relate to safety. This includes wind considerations (surface and ballistic), visibility (ceiling for skyscreens and visual for aircraft) and temperature considerations.
(11) Flight Safety Plan - The trainee must become familiar with the Flight Safety Plan. After satisfactory completion of the above steps 1-10, he will be expected to write a Flight Safety Plan for a specific mission. This plan includes information concerning the nominal trajectory, impacts and dispersions, hazard areas, flight safety limits, operational safety procedures, clearance and surveillance, weather limitations and Command System requirements (if applicable).
(12) Data Sources and Displays - The trainee must understand and be able to interpret data sources and displays. He will become familiar with radar data (present position, flight azimuth and elevation), radar via real-time computer (velocity, IIP and digital displays), telemetry (pitch program, longitudinal acceleration and command channel), skyscreens (location, purpose and reporting procedures) and camera requirements.
(13) Command System - The trainee is instructed on the use of the Command/Destruct System employed at the WFF. This includes a description of the FRW-2 transmitter system, understanding why it is required on guided vehicles, destruct criteria, FRW-2 status monitoring, power versus range considerations and over the horizon capabilities.
(14) Range Safety Display System - The trainee will be instructed on the setup and use of the display system used at the WFF. This will include information concerning tracking data, destruct lines, IIP plots, wind weighting considerations and simulation techniques and capabilities.
(15) Control Center Operations - The trainee will be instructed on the use of the operations control area. Supporting personnel and their roles in the safety process will be defined. This includes communications,

surveillance, skyscreen, etc..

(16) Failure Modes - The trainee must understand the various failure modes that can come into play during the flight of a vehicle. These can be categorized as: catastrophic, pitch over shoulder, pitch program failure, control system failure (yaw), rocket motor failure, FRW-2 command system (backup system and alternate site), radar (loss of track and side lobe), computer failures, display system failures, communication system failures and power failures. The trainee must be able to understand the repercussions of any of these failures and act accordingly.

(17) Pre-Mission Briefing - The trainee is required to present a pre-mission briefing to safety and operations personnel prior to conducting a specific mission.

(18) Range Safety Officer Simulations - The trainee must be able to complete, successfully, a variety of simulated runs of malfunctioning vehicles under different conditions and failure modes.

This includes off-nominal trajectories, ground and vehicle instrumentation system failures, Range Safety Display System failures, etc..

(19) Certification - The WFF safety office does not certify, formally, their Range Safety Officers. However, upon completion of the RSO training program, the duties of RSO are added to the individual's position description which serves as a permanent record. The WFF safety office provides training and formal certification for internationals. They are certified, formally, by the Director, Suborbital Projects and Operations Directorate, by letter.

c. Range Safety Officer Checkout - Under the supervision of an experienced RSO, the newly qualified RSO must perform in a manner consistent with Range Safety policies and procedures. He will be evaluated and a determination made as to whether or not additional training is required.

d. Recurring Training - As required, proficiency or recurring training is provided to the Range Safety Officer.

e. Training Timetable - The amount of time required to train candidate RSO's varies, depending on the individual's capabilities and the available launch schedule.

However, the typical time schedule for RSO training at the WFF is approximately one year from the time the trainee enters the program until he is qualified to man the RSO console.

4. Range Safety Systems and Support Personnel[20] - The Range Safety System (RSS), located in the Range Control Center (RCC), provides the RSO with the capability for monitoring launches and other special tests. **Figure 15**[10] shows a layout of the RCC. Supporting elements of the RSS such as tracking radars, telemetry instruments, the command transmitters and optical equipment are located at sites on the Wallops Mainland, at Wallops Island and downrange at Bermuda. The RSS and supporting personnel consist of the following:

a. RSO Console - This is the focal point for Range Safety functions during launch operations. It is manned by the Senior RSO and primary RSO. The RSO console provides the following: 1) - launch vehicle present position and predicted impact point data displays for comparison with flight termination criteria, 2) - video monitors displaying various television camera views of the vehicle in flight, as well as launch area conditions, 3) - range "Holdfire" control and indicators, 4) -control units to initiate flight termination action, 5) - voice communications with other Range Safety personnel, WFF controllers, launch agency controllers and other stations as required and 6) - the ability to compute, in real-time, limits of acceptability which follow allowable Range Safety criteria.

b. Range Safety Display System (RSDS)/RSO - The RSDS is located in the RCC and consists of dual consoles, each with four monitors whose displays are real-time selectable by the SRSO or RSO. These are redundant systems as are all elements of the Range Safety system. The RSDS allows continuous monitoring of vehicle performance by the SRSO and RSO to determine whether vehicle behavior is nominal. Data available to the SRSO/RSO include vehicle Instantaneous Impact Point (IIP), Present Position (PP), destruct lines and background maps. Alphanumeric data in the left and right margins of the displays provide information concerning vehicle tracking sources, vehicle altitude, velocity, heading, etc..

Additionally, multiple sensor (radar) tracking data is input from the Range Safety computer to the RSDS. This allows the RSO to have two independent tracking sources to compare. Though there is a multiplicity of data and tracking information available to the RSO, it is important to recognize that the RSO must exercise his judgement in making a decision to terminate vehicle flight.

(1) Displays - Tracking information is displayed on the RSDS monitors. Each system (A and B) drives four of the eight monitors on the RSO console to preclude loss of all display capability from any single failure. Each monitor is independently controlled by an individual function keyboard which selects formats for display.

(2) RSO - He is responsible for monitoring displays during real-time flight to evaluate tracking and performance data. The RSO works in conjunction with other supporting personnel (i.e., Senior RSO, Radar Coordinator, Test Director, Skyscreen, etc.) during launch operations in order to provide the greatest amount of coordination possible.

(3) SRSO - He assists the RSO with problems encountered during the prelaunch countdown and, when time permits, provides information and concurrence with the decision to terminate vehicle flight. The SRSO has the authority to "overrule" any decision the RSO may have made. The SRSO monitors displays and communications with safety personnel and other support organizations.

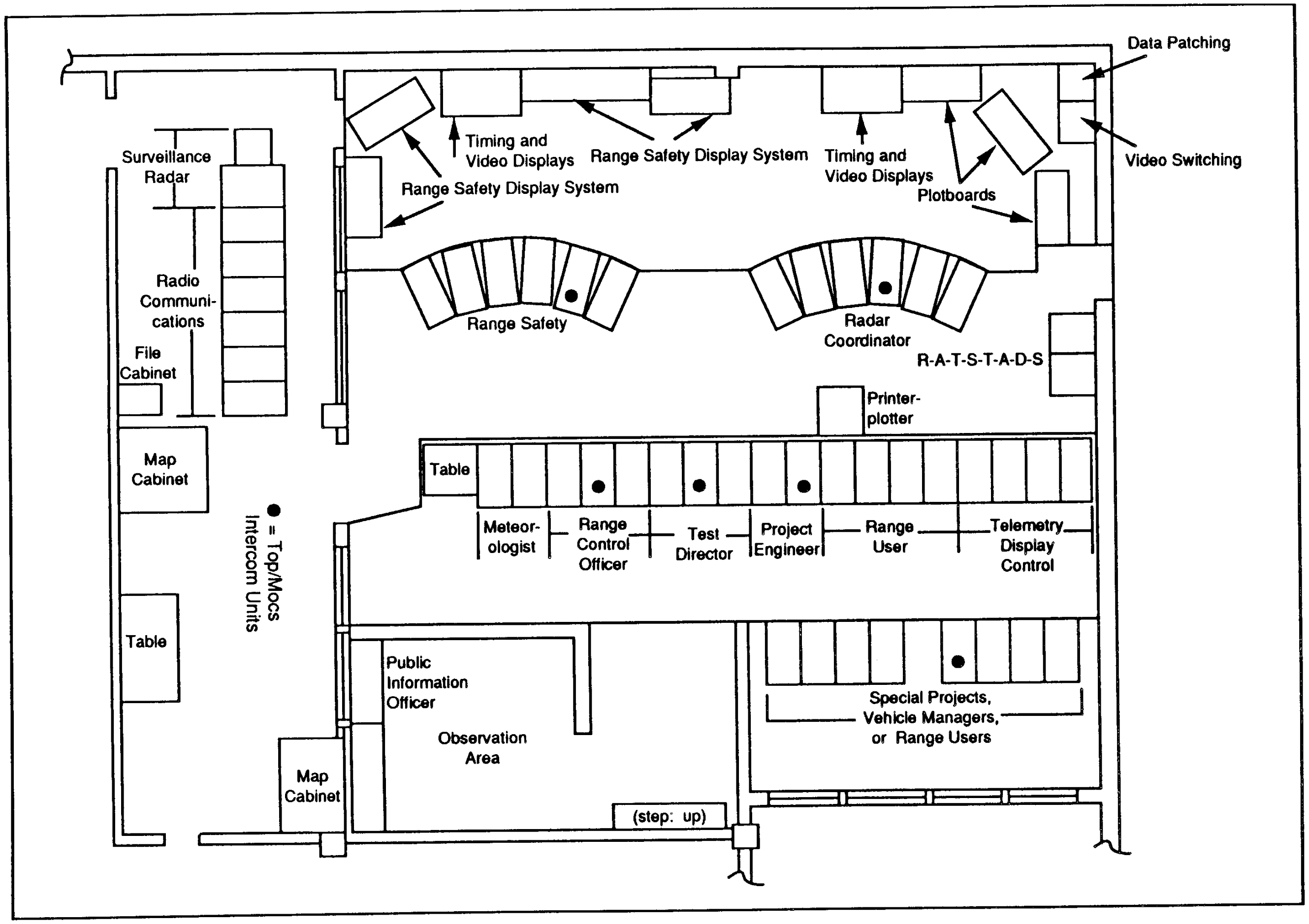


FIGURE 15. WFF RANGE CONTROL CENTER

c. Command/Destruct System - The transmitter site maintains two independent command systems which are electronically linked to the Range Safety Officer's console during an operation, and whose antennas track the vehicle during flight. (Specifically, they are provided pointing data from the tracking radars). Two monitor channels are used to verify that the transmitters are locked onto the command receivers in the vehicle. The Range Safety Officer can send a destruct command using a two step procedure:

(1) ARM DESTRUCT SYSTEM

(2) SEND DESTRUCT COMMAND

In case of an electronic failure between the Control Center and the transmitter site, the RSO can instruct transmitter site personnel to send the destruct command.

Flight safety limits are established for each flight. Vehicles that violate the flight safety limits create an immediate safety hazard and must be destroyed. During flight, the Range Safety Officer must evaluate whether the vehicle is violating the flight safety limits. He does this by observing and evaluating his data sources.

Normally, the RSO will not destroy the vehicle on the basis of one data source; he will try to verify a failure from several different data sources. This is one of the reasons why there are multiple, and sometimes redundant, data sources. Additionally, this provides backup data sources in the event of a failure. Also, the RSO must have sufficient time to evaluate data when a potential exists for a destruct situation.

The RSO must be aware of the effective range of the command/destruct system. He must assure that the vehicle is within command range at all times. For some missions, this requires having another command system downrange. Bermuda is sometimes used for this purpose. Through a telemetry channel, the RSO can monitor commands being sent and these commands can be recorded for a permanent record.

d. Range Safety Telemetry Display System - This system provides real-time telemetry which is used to monitor vehicle performance. Such events as stage ignition can be verified by telemetry data. A specific example being that a vehicle's pitch program can be monitored to verify that the guidance commands are being generated. Pitch, roll and yaw data is displayed in order to assess vehicle attitude. The command/destruct monitor channels provide the RSO with information on the transmitter carrier, and whether or not the system has been armed. Besides displaying vehicle data, telemetry data can be used as a back-up source to confirm a vehicle failure. The telemetry data can be displayed in the Control Center or can be communicated by intercom to the RSO from Range Safety personnel located at the telemetry site.

The telemetered data is not used as an input to the Range Safety computers for computation of the vehicle's IIP.

e. Radar Tracking Systems - Radar tracking systems are the primary data sources used by Range Safety with real-time vehicle radar tracking data being routed to the Range Safety computers for processing. Azimuth, elevation and range data are fed into the computers for calculation of IIP data. This information, along with velocity data, is transferred to the RCC and formatted in the RSDS computers for display to the RSO.

Range support personnel perform prelaunch testing of the radar network and verify that all critical support requirements are met. During real-time operations, the Radar Coordinator controls the radar systems and, in the event of a radar malfunction or tracking problem, selects alternate sources to assure that information is constantly available to the RSO.

f. Optical Systems - Multiple cameras provide real-time video of the launch vehicle for use by the RSO. Azimuth and elevation angle data is not provided to Range Safety for use in computing Instantaneous Impact Point information.

g. Skyscreens - Skyscreens are visual data sources used to observe vehicle trajectories during the early stages of flight (approximately 0-15 seconds). Skyscreen personnel, who are in radio contact with the RSO, detect vehicles violating the flight safety limits and report this information to the Range Safety Officer. The skyscreen locations are approximately 1 to 2 miles from the pad.

h. Surveillance Control - The central control station for surveillance is located in the RCC and is operated by Range Safety personnel. The surveillance control representative monitors sea (ship and boat) traffic in the predetermined hazard area. If hazards exceed an acceptable level ($1x10^{-5}$), the RSO waits until surface vessels move to a safe position. If hazards cannot be reduced to an acceptable level, the RSO may call a hold to the launch countdown until hazards are clear. Voice communications are provided to supporting surveillance aircraft, radar sites and air controllers.

Surveillance radars are used to control impact risk for launches from WFF. Radar systems such as a Mariners Pathfinder, ASR-7 and APS-128E or APS 80, are employed to determine the location of ships and aircraft. These radar systems survey impact areas out to approximately 100 nautical miles. Using the ship data reports, the RSO can determine if ship impact criteria are satisfied. If the criteria are satisfied, the launch may proceed.[21]

i. Emergency Response - The Chief, Health, Safety and Security Office, works for Industrial Safety and is responsible for directing Crash, Fire and Rescue Company efforts and mutual aid support, as required, in the event of an explosion, fire or errant vehicle, both on and off WFF property. In addition, he insures that Crash, Fire and Rescue Company personnel respond to directives issued by the RSO and/or Test Director during launch operations or emergencies.[18]

The Crash, Fire and Rescue Company is an organization hired to perform these functions should a malfunction occur which results in unplanned impact, explosions or fire. A recovery team normally consists of these people, augmented by personnel from Launch Operations, Security and Safety.

5. Safety Restrictions - Safety restrictions are established by Range Safety personnel for the launch vehicles launched from the WFF. In general, the vehicles must be launched in an easterly or southeasterly direction and on an azimuth that provides protection for land masses and populated areas from debris. All flights are planned in accordance with impact agreements and conducted so that the planned impact or reentry of any part of the launch vehicle over any land mass, sea or airspace does not produce a casualty expectancy greater than 10^{-7} and an impact probability on private or public property, which might cause damage, greater than 10^{-3}, unless a Safety Analysis Report is prepared and approved, or it can be proven that:

- The reentering vehicle will be completely consumed by aerodynamic heating, or
- The momentum of solid pieces of the reentering vehicles (balloons, parachutes, etc.) will be low enough to preclude injury or damage, or
- Formal Government or private agreements allow the use of the land mass for impact or reentry.

No vehicle may overfly a populated area in violation of previous Governmental or private agreements unless the vehicle is in orbit or the probability of an overflight failure does not violate impact criteria, or unless approved in a Safety Analysis Report.[18]

a. Flight Azimuths - For Scout vehicles, launch azimuths between 109^0 and 126^0 are restricted due to the fact that the second stage has an unacceptably high probability (greater than 1.0×10^{-3}) of impacting on the Island of Bermuda. However, flights on these azimuths are not always ruled out (a Safety Analysis Report might be approved).[3] Refer again to **Figure 6** for a graphical representation of the restricted flight azimuths. Sounding rockets are restricted to azimuths normally ranging from 90^0 to 165^0.

b. Launch Area - Other restrictions established by Range Safety include:

(1) Danger Areas - That area, including impact areas, abort areas or malfunction debris or hazard areas, in which the hazards from launch vehicle stages, debris or toxic materials exceed the established maximum, acceptable risk level.

Procedures for determining the explosive and flight control hazard areas are briefly described below:

- Explosive Hazard Area - The danger area for any given vehicle launched from the Wallops range can be described as a circle around the launch pad. It is common practice to use the following formula to determine this distance:

$$\text{Distance (D)} = 80\,(\text{Total TNT equivalent weight of propellants})^{1/3}$$

Typical explosive hazard areas range from approximately 390-1250 feet.

- Flight Control Hazard Area - This area is vehicle dependent in that it is directly related to vehicle performance parameters, i.e., acceleration. Fragment data is not used in the determination of this hazard area. Known trajectory data is simulated to build malfunction turn information necessary to define this area. The Flight Control Hazard Areas range from approximately 3000-6000 feet and are oval in shape.

(2) Danger Time - That time period when any electrical operation, arming, explosive installation, launching or other dangerous function is taking place.

(3) Caution Time - That time period when any explosive devices are in the launch area. When a caution time exists, nonparticipating

personnel are allowed to enter a launch area only when authorized by the Pad Supervisor. Active-essential and standby-essential personnel continue working during a caution time.

(4) Active-Essential Personnel - Those individuals whose activities contribute directly to the preparation of a launch vehicle or support equipment for a specific operation which is actually under way, and whose presence is mandatory for completion of the operation.

c. Impact/Hazard Areas - Impact Areas are calculated for expended booster stages, payload fairings or any other significant parts that are jettisoned along the planned flight path. Examples of impact areas for items jettisoned from a Scout launch vehicle and a Black Brant X sounding rocket are shown in **Figure 16**$_{8}$ and **Figure 17**$_{17}$. These impact areas must be in the ocean. All impacts within the Virginia Capes operating areas (VACAPES) require clearance from Fleet Area Control and Surveillance Facility (FACSFAC) prior to launch. In addition, GSFC/WFF will request Notice to Mariners (NOTMARS) and Notice to Airmen (NOTAMS) to be issued prior to the launch date. All impacts outside VACAPES require clearance with the FAA. GSFC/WFF is responsible for obtaining this clearance, and to do this, Range Users are required to provide the predicted impact related dispersion data for each re-entering body. It has been common practice to apply an acceptable-risk, ship-hit criterion of one in one hundred thousand (i.e., 1x10^{-5}) to ships and boats.

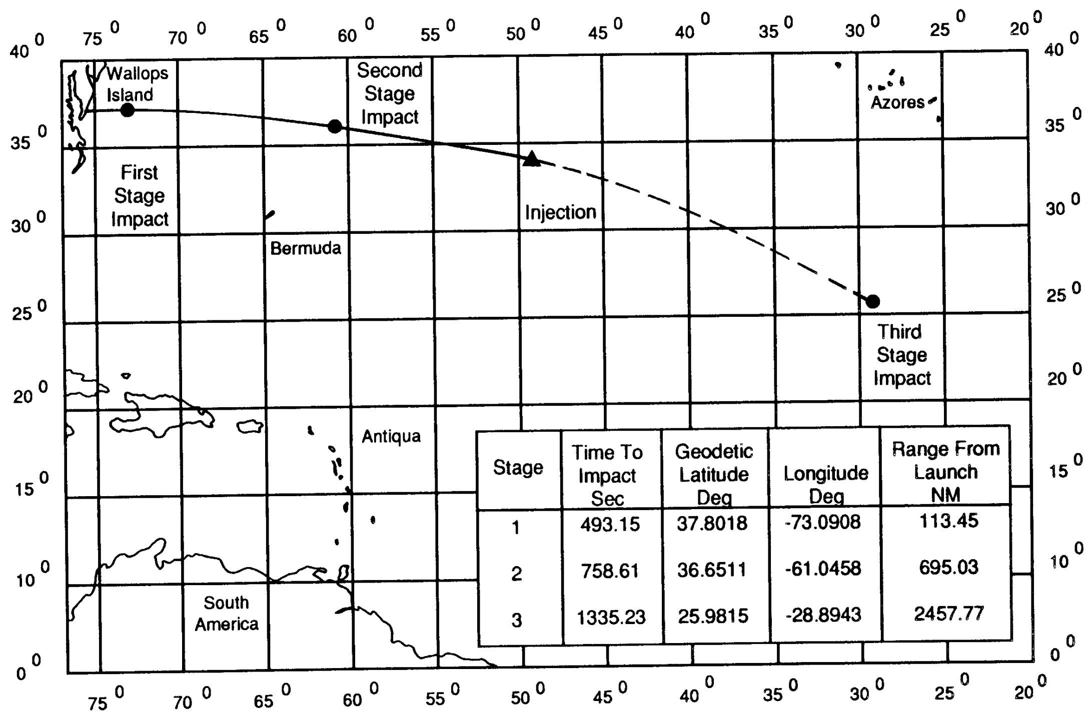
Because aircraft are more vulnerable than ships, an impact probability of one in ten million (i.e., 1x10^{-7}) is used. There has never been a confirmed report of a jettisoned vehicle part striking an aircraft or ship. The probability of an object impacting in a land area must be less than, or equal to, 1x10^{-3}.

(1) General - The operational hazard area is that area which must be kept clear of ships and aircraft. For unguided vehicles (most sounding rockets), the size of the hazard area is such that the probability of hitting a ship or aircraft just outside of the area is less than the accepted probability (1.0x10^{-5}). For guided vehicles with a destruct system, the destruct limits are calculated such that all impacts are contained within the hazard area.

Impact clearance must be obtained for the operational hazard area. Normally, additional area is obtained to provide for shifts in hazard area location and for use as a buffer. Clearance requests are normally based on the size of the aircraft hazard area since this area is normally larger than the ship hazard area.

For unguided systems, the operational hazard area is basically a function of two variables:

- Size of the impacting vehicle
- Dispersion



Stage	Time To Impact Sec	Geodetic Latitude Deg	Longitude Deg	Range From Launch NM
1	493.15	37.8018	-73.0908	113.45
2	758.61	36.6511	-61.0458	695.03
3	1335.23	25.9815	-28.8943	2457.77

FIGURE 16. SCOUT IMPACT DATA FOR JETTISONED ITEMS

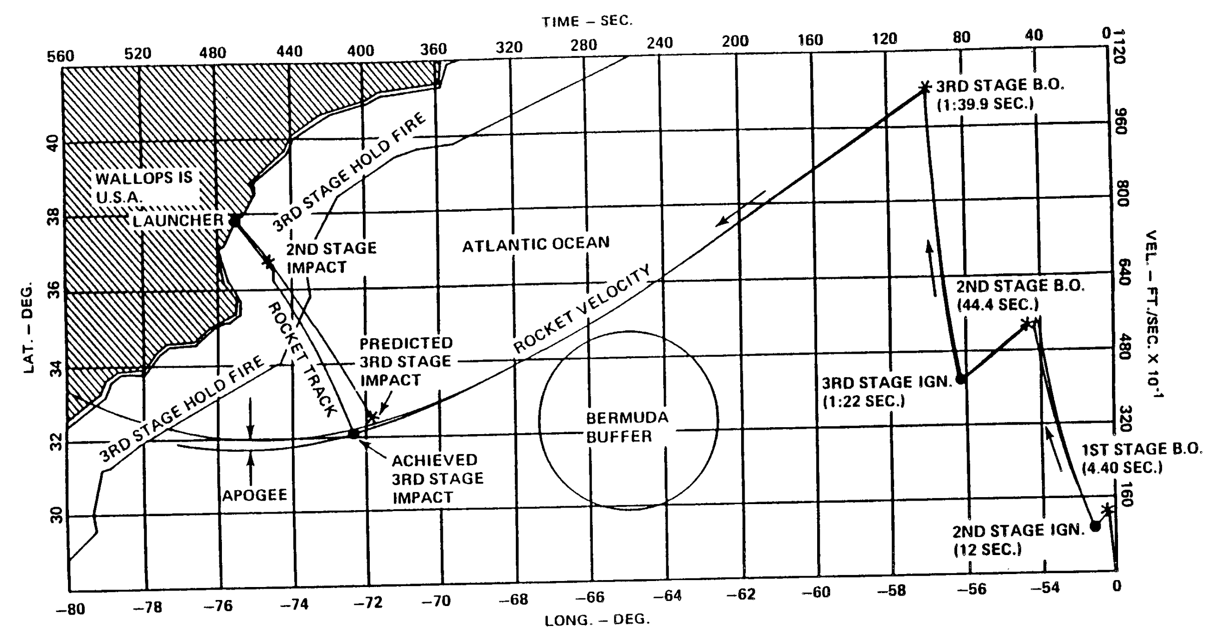


FIGURE 17. BLACK BRANT X IMPACT DATA FOR JETTISONED ITEMS

For guided systems, the hazard area is a summation of a number of components that result in a maximum deviation from the nominal flight path:

(a) Flight Control Corridor - Preprogrammed guidance systems cause the vehicle to fly a predetermined trajectory within a certain variance, usually identified by a 1-sigma variance.

(b) Data Source "Error" - The accuracy in which the Range Safety Officer knows the location of the vehicle (radar/display accuracy).

(c) Turn Rates/Reaction Time - It takes the RSO a certain finite amount of time (usually 3-5 seconds) to detect a malfunctioning vehicle, determine that the flight safety limits are being exceeded and to initiate the destruct action. Turn rates are calculated to determine the maximum distance that an errant vehicle can traverse during this reaction time.

(d) Debris Drag Impact - This is the distance that the vehicle debris traverses after destruct has occurred. It is a function of four parameters: altitude, velocity, flight path angle and the drag coefficient of the debris particle with the furthest impact range. (Heavy particles with low drag go the furthest after destruct.)

(e) Buffer - A buffer is a "cushion" factor added on to a hazard area for such purposes as to compensate for inaccuracies in reporting the location of ship and air contacts and any uncertainties in the hazard area calculations.

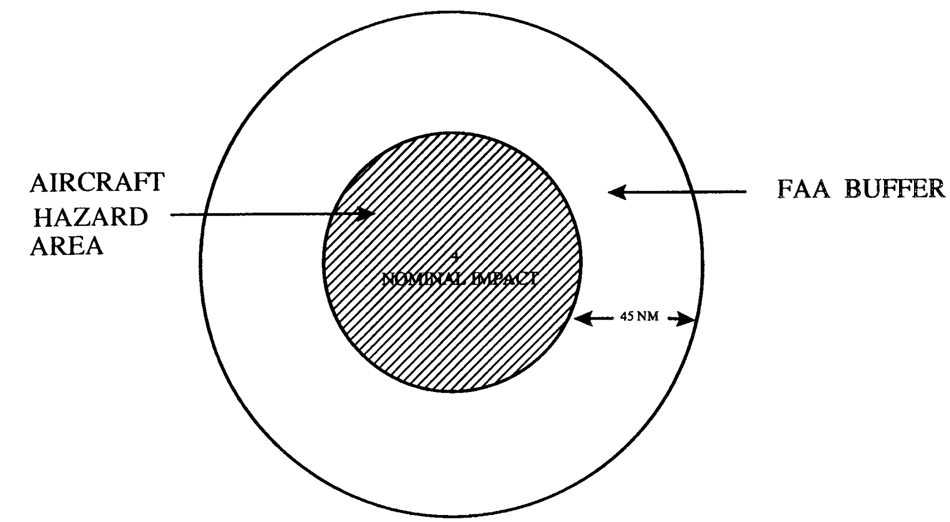
(2) Aircraft Hazard Area - Missile operations inherently produce a hazard to aircraft in the vicinity of the vehicle impact area or spent stage impact areas. WFF's policy requires that an aircraft hazard area be established to protect aircraft and passengers against the risk of a vehicle/aircraft impact. A typical aircraft hazard area is shown in **Figure 18**$_{22}$.

WFF has an existing agreement with the FAA that specifies responsibilities and procedures for protecting aircraft during launch operations. This documentassigns WFF the responsibility for assessing the hazard to aircraft and for determining the size of the hazard area. The FAA routinely adds a 45 nm buffer to the Wallops hazard area.

Range Safety computes the aircraft hazard area based on the casualty expectancy criteria specified in GHB 1771.1 ($1x10^{-7}$). Use of this criteria can result in large hazard areas for vehicles with large dispersions.

(3) Launch Hazard Area - A launch hazard area for the Scout vehicle is defined as a circle with a 0.9 nautical mile radius centered on the launch pad. For other launch vehicles, this area is the "Inhabited Building Distance" (defined in AFR 127-100) as determined by the amount of vehicle propellant.

(4) Sounding Rocket Dispersion - Dispersion of the impact location of a rocket is the statistical deviation of the actual impact point from the nominal impact point due to uncertainties in modeling parameters (e.g., wind). It is used to calculate the probability of impacting within a given distance of the nominal impact point. This distance is commonly expressed as a sigma value (the square root of the average of the squares of the deviations from the mean).



Note: Aircraft Hazard Area is based on 1.0X10-7 Hit Probability to Aircraft

FIGURE 18. AIRCRAFT HAZARD AREA

The probabilities of impacting within the indicated sigma values for a circular dispersion are:

1 sigma	0.393
2 sigma	0.865
3 sigma	0.989

There are two commonly used methods of determining dispersion which are used at Wallops and are discussed in the following paragraphs:

• Theoretical Dispersion - The theoretical dispersion is determined by varying each of the parameters that affect impact range or azimuth. Typical parameters that are used to determine dispersion characteristics of multi-stage sounding rockets include: thrust misalignment, wind error, weight error, drag error and elevation error. Each parameter is varied by an amount determined by engineering experience to be approximately the same sigma value as will be used to define the dispersion. Computer runs are then made to calculate the difference in impact points for each parametric variation.

The total dispersion is determined from the individual parameters using the root means square (RSS) method.

$D = (D^2 1 + D^2 2 + ... D^2 i)^{1/2}$

The dispersion for a guided rocket is calculated similarly. In general, a guidance system is pre-programmed to cause the rocket to fly a certain trajectory. The variability of this trajectory depends on how accurately the guidance system can detect deviations from the nominal trajectory and the capability of the control system to adjust the vehicle flight to correct these deviations.

• Flight History Dispersion - The flight history dispersion is determined by comparing the actual impacts to the predicted impacts. This method yields good dispersion numbers if a sufficient number of flights for a similar payload weight and launch parameters are available.

(5) Wind Effects for Sounding Rockets - Wind can significantly affect the flight of rockets. Unguided rockets must be wind-corrected to fly the planned trajectory. Prelaunch winds (initially taken at approximately 3 hours prior to launch) are used to determine the launch azimuth and the launch elevation angle which will result in the vehicle flying the desired trajectory. High or gusty winds (on the order of 30-35 mph or gusts above 45 mph) may make it unsafe to launch a rocket. Even for guided rockets, the winds may get so strong that they saturate the vehicle guidance system. A rocket is normally wind-corrected so that the desired trajectory is achieved and the predicted vehicle impact of the last stage is in the planned area. This may not result in the booster stage impact being in its original planned impact area. Separate booster wind correction and drift calculations must also be made to determine it's impact location and to assure that the predicted booster impact location is in a safe area.

Wallops Range Safety personnel use a 5-degree of freedom computer program named SENSE 5D, which is tailored after the Lewis or Unit Wind method, to aid in determining the proper launcher settings to be used for any given sounding rocket mission. This wind weighting procedure is used prelaunch as a predictor.

Parameters such as:

- Tower Tilt - number of nautical miles per degree of elevation,
- Ballistic Wind - sum of the weighted winds for each altitude layer
- Unit Wind - number of nautical miles per feet per second of the ballistic wind
- f curve - the sensitivity of the launch vehicle to wind versus altitude are computed by the SENSE 5D computer program and are used in determining the adjustments to the launch flight azimuth and elevation angles for sounding rocket launches.

During actual launch operations, the SENSE 5D program uses actual wind data taken from balloon tracking information and used to fine tune the launcher settings to obtain the desired trajectory and stage impact locations. Radar reflective balloons are released at predetermined times prior to the scheduled launch time. Also, there is an occasional use of radiosonde equipped balloons for this purpose. These balloons are tracked by radars located on the Wallops range. This tracking information is received/processed and used in the SENSE 5D computer program, which outputs the appropriate launcher settings necessary to compensate for the "actual" winds and achieve the desired trajectory and stage impact locations. These balloons are released and tracked to the burnout altitude of the final stage or a maximum of approximately 100,000 feet in altitude. Low altitude (< 300 feet) wind data is obtained from anemometers mounted on towers located at various places on the Wallops range. As launch time approaches, balloons are only tracked to 5000 feet with the last one released at approximately 15-20 minutes prior to launch. With an ascent rate of approximately one thousand feet per minute, this allows ample time for processing of radar tracking data and subsequent determination of appropriate launch parameters as near to launch conditions as practical.

An example of a wind weighting calculation for a typical sounding rocket second stage is shown below:

To compute the adjustments to vehicle flight azimuth and elevation angle required to compensate for wind, it is first necessary to select the altitude levels that are representative of the mission. The Black Brant X vehicle is used for this example.[35]

The change in vehicle sensitivity (Delta F), see **Figure 19**, to the wind in the appropriate altitude level is multiplied by the N/S and E/W wind profiles (shown in the table below) to obtain the ballistic wind for each altitude level selected. It is important to note that approximately 80% of the wind effects occur during the first stage flight of a sounding rocket.

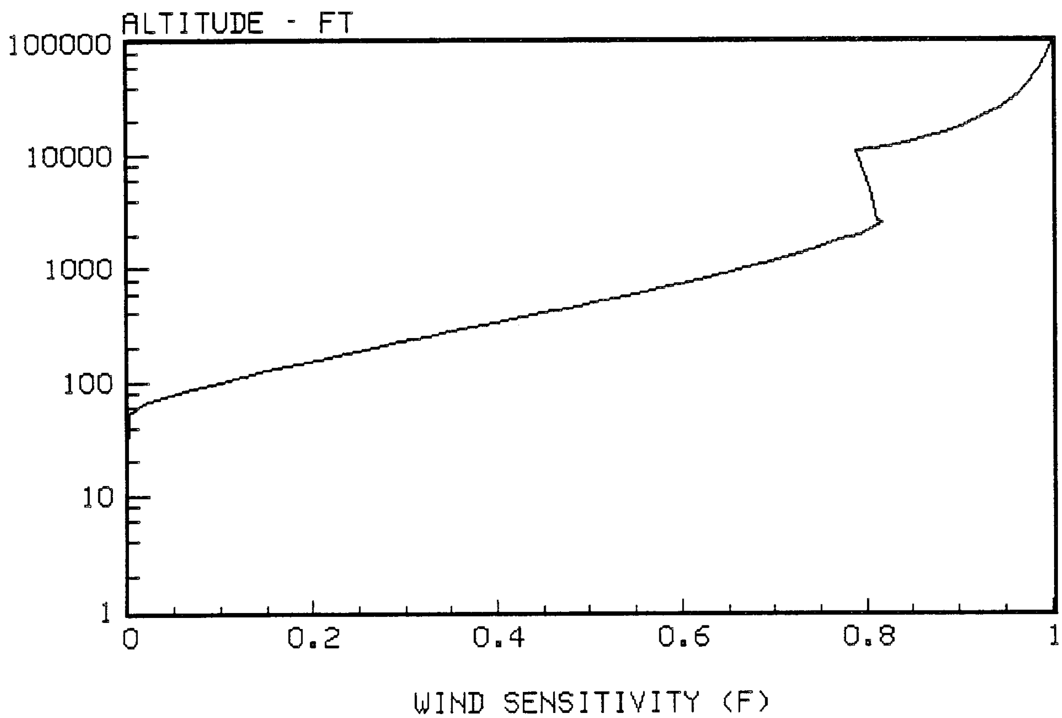


FIGURE 19. VEHICLE ALTITUDE VS WIND SENSITIVITY

Table 6 below shows the altitude levels, vehicle sensitivity (Delta F)/altitude interval, N/S and E/W wind profile and the resultant ballistic winds used for this example.

TABLE 6. WIND WEIGHTING DATA					
ALTITUDE (FT)	ΔF VS ALT LAYER	ACTUAL WINDS		BALLISTIC WIND	
		N/S	E/W	N/S	E/W
		$\dot{X}$ FT/SEC	$\dot{Y}$ FT/SEC	$W\dot{X}$ FT/SEC	$W\dot{X}$ FT/SEC
33 - 100	.100	20	-20	+2.0	-2.0
100-225	.194	21	-25	+4.1	-4.9
225-400	.153	22	-20	+3.4	-3.1
400-800	.171	28	-15	+4.8	-2.6
800-1600	.136	35	-10	+4.8	-1.4
1600-2500	.064	50	-15	+3.2	-1.0
2500-10,914	-.029	-20	-20	+0.6	+0.6
10,914-16,000	.097	-45	45	-4.4	+4.4
16,000-27,500	.063	-50	20	-3.2	+1.3
27,500-45,000	.029	-28	25	-0.8	+0.7
45,000-98,836	.022	-22	15	-0.5	+0.3
Totals	1.000			+14.0	-8.0

The individual ballistic winds are then summed to obtain the total effect of the N/S and E/W wind profiles, i.e. +14 for N/S (from the north) and -8 for E/W (from the west) in this example. The total ballistic wind for the N/S (+14) and E/W (-8) components is then multiplied by the appropriate unit wind factor for crosswind (2.0 N/S) and tailwind (1.96 E/W) obtained from reference 31. This is shown in the following expression:

N/S component = +14 ft/sec X 2.0 nm/ft/sec = +28 nm
E/W component = -8 ft/sec X 1.96 nm/ft/sec = -16 nm
This will have the effect of driving the impact point from the desired location as shown in **Figure 20** below:

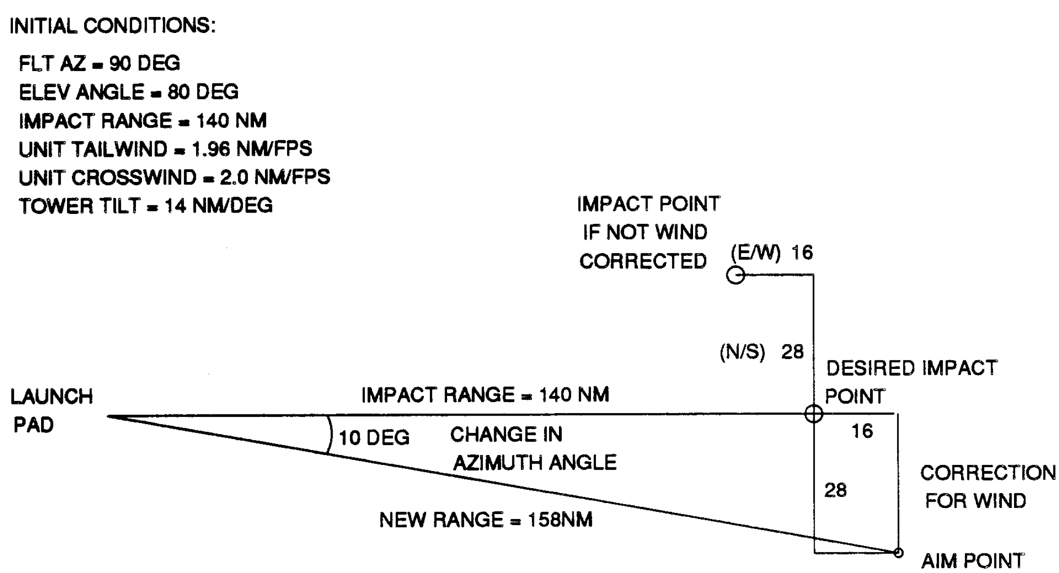


FIGURE 20. SECOND STAGE IMPACT POINT WIND CORRECTION

In order to compensate for the wind effects, the flight azimuth and elevation angles must be adjusted. First a computation must be made to determine the new range component which has resulted from the wind effects. This is found by:

$R^2 = (156 \text{ nm})^2 + (28 \text{ nm})^2$

$R = (24{,}336 + 784)^{1/2} = 25{,}100^{1/2}$

$R = 158 \text{ nm}$

Next it is necessary to compute the change in the flight azimuth. This is done by solving for the angle made between the launch point and the adjusted aim point shown in the above figure. Since the sine of the angle = 28 nm/158 nm = .1772, then the change in the flight azimuth is approximately 10^0. Therefore, $90^0 + 10^0 = 100^0$ which is the adjusted flight azimuth for this example.
To find the new launch elevation angle the following expression is used: El angle = New Range/Tower Tilt = 158 nm/14 nm/deg_{35} = ~11.3^0 The adjusted elevation angle is then, $90^0 + (-11.3^0) = 78.7^0$ Hence, the vehicle must be launched on a flight azimuth of 100^0 (to compensate for wind effects) with an elevation angle of 78.7^0 (to compensate for the increased range) to obtain the desired trajectory and impact point at 140 nm. The adjustments to the flight azimuth and the elevation angle has a direct effect on the first stage nominal impact point. The new impact point must be determined and appropriate action taken by range safety personnel to assure that the impact location is clear of boats, ships and aircraft during sounding rocket launch operations.
d. Impact Limit Lines - The Impact Limit Lines (ILL) define geographical areas to be protected during launch. The Instantaneous Impact Point (IIP) is the point at which a rocket would impact if it stopped thrusting at a given time (assuming a ballistic trajectory to impact). The IIP coincides with the nominal impact point after nominal burnout. In the immediate launch area, the ILL's are selected in order to provide protection for critical and/or expensive facilities and public areas that could be exposed to risks associated with launch operations. The public is normally excluded from sites that are within the ILL and, hence, the public risks are negligible. The IIP prediction capability can be used as a real-time tool by the RSO. The RSO can determine at any time during the flight where the impact would occur if the vehicle flight were terminated at that time. Since this information is based upon the actual position of the vehicle, the dispersion factor is not considered for the destruct limits on the IIP display. If the IIP track is heading towards a land area, the RSO can send the destruct command when the IIP track crosses the destruct line. The IIP track is also used to compute dwell time over a land area (either prelaunch from nominal data or in real-time) by the RSO.
e. Orbit Predict - As an example of Orbital Prediction, the Scout orbital parameters can be predicted once the third stage burnout parameters are known. This prediction technique assumes a nominal fourth stage performance. There is an orbital injection "window" that the vehicle must pass through if it is going to achieve a satisfactory orbit, i.e., a perigee of at least 50 nautical miles. If the flight elevation angle is too high or too low at fourth stage ignition, the vehicle will not achieve orbit. If it does not achieve orbit, the fourth stage plus payload will impact somewhere on the first pass around the earth.
The predicted orbital parameters can be displayed after third stage burnout. If the predicted perigee is less than 50 nautical miles, the payload will not achieve a satisfactory orbit and the vehicle is destructed. An example of the orbital parameters displayed to the RSO are:

- Velocity (at fourth stage burnout)
- Apogee

- Perigee
- Orbit Inclination
- Latitude (fourth stage impact)
- Longitude (fourth stage impact)

f. Destruct Lines - Destruct lines, or flight termination lines, define the flight limits used for terminating vehicle flight. Activation of the FTS by the RSO upon violation of the destruct lines prevents significant debris from penetrating the ILL. Destruct line location is determined by accounting for system delays, data inaccuracies (includes tracking system errors) and debris dispersions. Destruct lines are constructed between the nominal trajectory and the ILL. If the IIP crosses the destruct line and flight termination action is taken, the significant launch vehicle fragments will not impact beyond the ILL. As an example, **Figure 21**$_3$ shows a typical set of sounding rocket destruct lines.

g. Mission Rules - The Mission Rules are documented in the Flight Safety Plan developed for each mission and is coordinated with the operations branch head. Representative mission rules for a vehicle launch are as follows:

(1) Standard Rules

(a) Violation of fixed "destruct lines" will result in termination of vehicle flight.

(b) Violation of immediate launch area present position destruct criteria will result in termination of vehicle flight.

(c) If the vehicle performance is "Obviously Erratic" (out of control) and further flight is likely to increase the hazard, the RSO, based on his judgement, has the authority to terminate flight. This could occur by either interpretation of displayed data or by reacting to verbal calls from the Skyscreen Observer.

(d) If vehicle tracking status becomes "unknown" and the capability to violate an ILL exists, the RSO will make a judgement whether or not to terminate flight. If the vehicle performance has been normal after launch for an extended period of flight (which is not defined) prior to becoming unknown, the RSO may elect to allow the flight to continue. The RSO must evaluate all performance parameters and available data, and determine whether mission rules can be violated or if potential exposure to the public domain necessitates destruction of the vehicle.

(2) Scout Vehicle Unique Mission Rule (an example of a Mission Rule tailored for a specific launch vehicle) - Due to the nature of the Scout vehicle and the launch trajectories that are flown from WFF, it has been determined through analysis that no destruct action will be taken after nominal 3rd stage burnout. If it is determined in real-time that a proper orbit cannot be attained, transmission of the destruct command to the 3rd stage will be made, thus inhibiting 4th stage ignition.

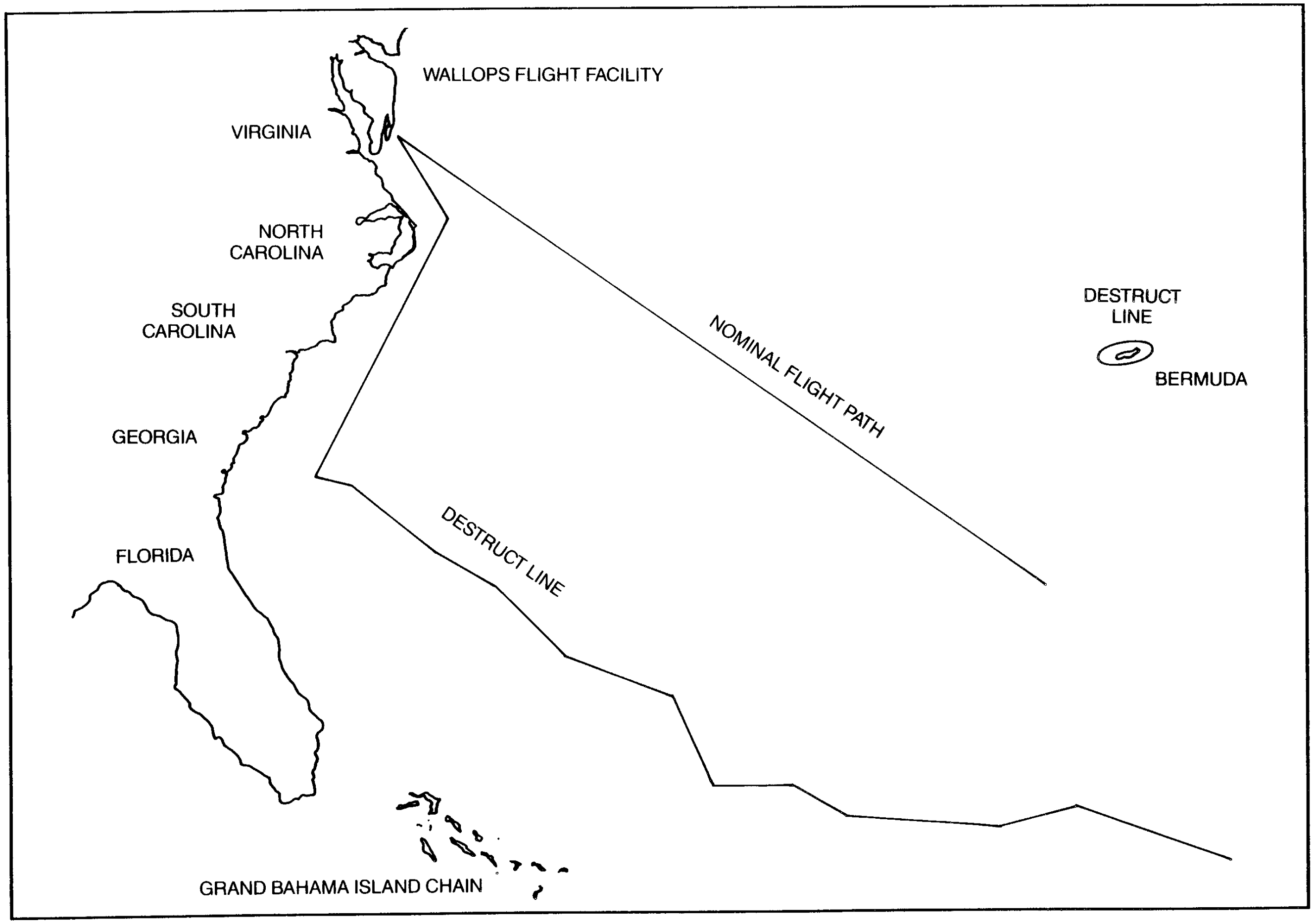


FIGURE 21. TYPICAL SOUNDING ROCKET DESTRUCT LINES

h. Range Safety Priority Items - For each mission, the Range Safety Officer determines the priority items necessary to meet minimum safety requirements. These items are normally documented in the Operations Directive for a particular program, vehicle or mission. There are three levels of priority items:

Priority 1 - Required Operational for launch (Mandatory)
Priority 2 - Highly Desirable but not mandatory for launch
Priority 3 - Holds to the launch countdown will not be called for these items

The priority 1 items for the Scout vehicle are (they vary according to vehicle/mission):

(1) WFF Radar - Vehicle position data from one skin tracking radar through 1st stage separation and vehicle position data from two beacon tracking radars through 3rd stage burnout
(2) WFF Command System - Command/Destruct
(3) WFF Main Base Telemetry - Vehicle telemetry data and spacecraft telemetry data
(4) WFF HW RADAC - Impact prediction data
(5) WFF Camera Stations - Documentary
(6) WFF Surveillance Aircraft - Ship Traffic Data
(7) WFF/NASCOM Communications - RSO voice, Countdown/Radar phasing
(8) Bermuda Radar - Vehicle position
(9) Bermuda Telemetry - Vehicle Telemetry Data
(10) Bermuda Command System - Command/Destruct
(11) Weather Constraints

6. Safety Analysis Report

a. Introduction - The purpose of this section is to present a baseline of the public risks for orbital launches from the WFF. The generic risk assessment presented herein is based on the facility's experiences, current commercial launch vehicle characteristics and experiences of the RTI staff. It must be noted that the WFF and other ranges adopted a FTS or "Command Destruct" philosophy in the early 1960's.

This philosophy has always assumed that the Flight Termination System (flight and ground components) provides an acceptable control methodology to prevent unacceptable public exposure from the launch of vehicles. Hence:

(1) Most public risk studies performed by the ranges are based on the assumption that the FTS prevents unnecessary public exposures.
(2) The reliability of the FTS (not the reliability of the launch vehicle) was assumed to be the controlling factor in assuring that public exposures did not occur.
(3) The FTS is utilized to prevent launch vehicles from exposing the public to risks from an errant vehicle and to disperse vehicle propellants in the event of a launch failure.

(4) As shown later, the public risks are primarily controlled by FTS system reliability (not launch vehicle failures) as assumed by the launch ranges.[23]

b. WFF Launch Experience - Following is a brief discussion of the WFF experiences in providing range safety protection during vehicle launch operations:

(1) The WFF has been conducting launches of various rockets and other vehicles since the mid 1940's. Most of the procedures and public safety criteria utilized by the WFF were developed over years of experience. The procedures and criteria for public safety that are utilized to protect the civilian community were evaluated by the Range Commander's Council and the subordinate Missile Flight Safety Group in the early 1960's, in which WFF played an active part.

The WFF has conducted the first launch of most of the research and development rockets used to determine and evaluate the effects of the natural environment on launch vehicles and spacecraft and to increase the knowledge of the Earth's upper atmosphere and the near space milieu. Approximately 2,500 of these types of launches have been performed over the last 30 years (1959 - 1989) by the WFF. The launching of the Scout vehicle for the purpose of placing spacecraft in orbit began in the early 1960's.

Flight safety rules were established for these missions, as well as the design specifications for the flight safety systems utilized to provide public protection.

(2) The Range Safety system at the WFF has accommodated only a few programs requiring destruct systems. These included the Scout, Aerobee, Athena and the Black Brant series of launch vehicles. Out of approximately 200 launches of vehicles (equipped with a FTS), only two reported cases involved an off-range impact.

These occurred during the early stages of the Aerobee program, and resulted in no property damage or injury to people (impact was in the water).

(3) Flight Termination System (FTS) Reliability -The actual flight history reliability for approximately 200 launches shows that no FTS failures have been recorded during these launches.

Since there were no recorded failures at WFF of the FTS system, a conservative estimate is to assume that a total FTS failure occurs on any subsequent launch. On this basis, the demonstrated FTS failure probability can be estimated to be 1/200 or $5x10^{-3}$ with high confidence and the FTS reliability is then; 1-1/200 = 0.995.

c. Public Exposures to WFF Space Launches

(1) Public Hazard Event Tree - The events required for an exposure of the public to a hazard from a space vehicle launch are depicted in **Figure 22**$_{23}$. The event tree shown illustrates the approximate probabilities and conditional events required to expose the public to a launch vehicle failure.

(2) Launch Vehicle Failure Probability/Reliability -The historical reliability and failure rates for the planned commercial launch vehicle (Scout) is shown below in **Table 7**$_{23}$:

TABLE 7. SCOUT LAUNCH VEHICLE RELIABILITY

Phase	Launches	Failures	Reliability %	Failure Rate %
Prior to Recertification (Dec. 1963)	23	10	66.5	43.5
Since Recertification (Dec. 1963)	89	4	95.5	4.5
Overall	112	14	87.5	12.5

The Scout launch vehicle has an overall reliability record of 87.5%. This record covers all launches of all Scout configurations, including development flights, since July 1960. Since the completion of the recertification program in December 1963, the Scout vehicle has demonstrated a reliability of 95.5%. The reliability of commercial launches is expected to continue at a comparable level since the same manufacturing, processing and launch specifications will be utilized. For Event #1 on the event tree, it can be assumed that approximately 95.5% of all Scout space launches are successful. This ignores those launches prior to recertification.

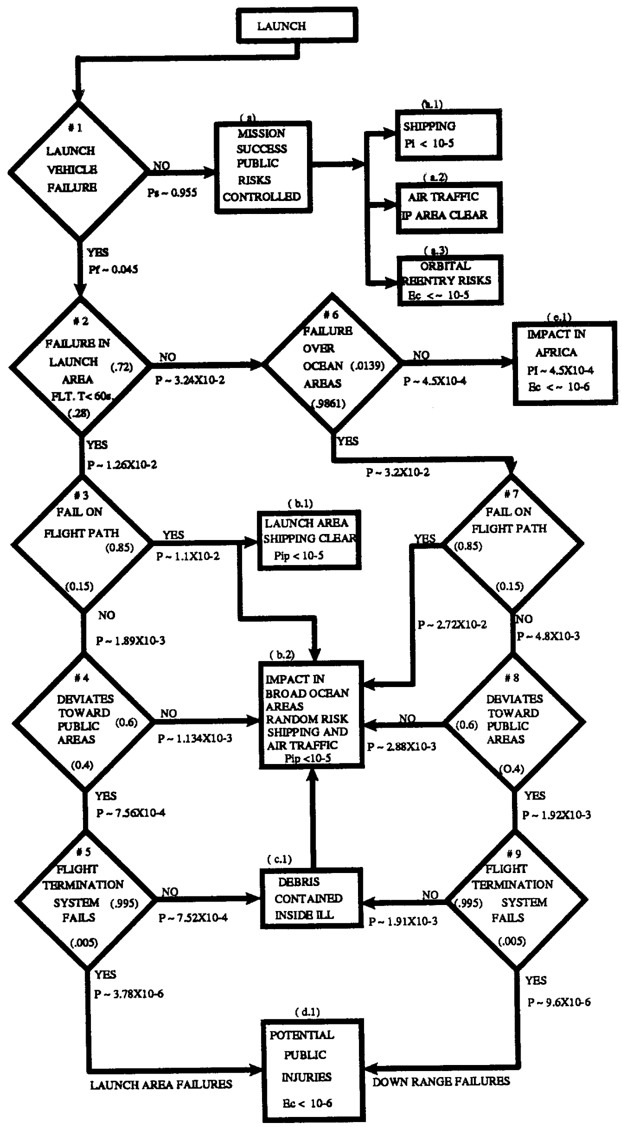


FIGURE 22. PUBLIC LAUNCH EVENT HAZARD TREE

A successful launch results in booster stages and other discarded debris impacting within planned areas and the eventual decay from orbit of all hardware placed in earth orbit. Shown by event tree boxes (a-a.3) are the results and estimated exposure levels for shipping and reentering debris. Planned Air Traffic exposures (a.2) are assumed to be less than 10^{-7}, since the FAA clears air traffic from all impact areas.

Approximately 4.5% of all Scout launch vehicles have failed since recertification and none of these failures occurred during the early launch phase, i.e., 0 to 60 seconds after launch. A conservative approach, however, would be to assume that the failure probability is evenly distributed over the thrusting periods of the solid rocket motors. On this basis, the conditional probability of a failure during the first 60 seconds is 60 seconds/215.6 seconds which equals ~0.28 or 28%. The remaining 72% of the launch failures occur downrange from the launch site and are controlled by Events #6 and #7. The conditional probabilities estimated at each event block are shown in parenthesis within the event block. Of those failures that do occur in the launch area, experience shows that approximately 85% of all launch vehicle failures occur on the original flight path (Event #3). Failures of the propulsion system(s) normally predominate the failure modes. Loss of thrust, loss of thrust vectoring, propulsion system explosions and vehicle structural failures due to turns result in little displacement from the original flight path. In many of these failures, complete destruction of the launch vehicle occurs before flight termination commands can be issued. The results of such failures pose a significant hazard to shipping near the launch site (b.1). Launch hazards to shipping and boating interests are controlled by surveillance out to a range of approximately 100 miles, depending upon the launch vehicle.

Hazardous areas are determined which show the permissible ship and boat locations and density to assure that the probability of impact on a ship or boat is less than 1×10^{-5}. Should failure and impact occur beyond the cleared shipping areas (b.2), studies have shown that shipping densities are such that the impact probabilities in the broad ocean areas are low and the probability of an impact is less than 1×10^{-5}.

Should the vehicle deviate from the flight path (3), the deviation can be in any direction. For WFF launches, approximately 60% of such failures would remain over the broad ocean areas and approximately 40% would be distributed toward populated areas protected by impact limit lines (Event #4). For those not deviating toward public areas, the outcome, (b.2), would result in little public risk whether or not destruct action is taken.

Launch vehicles that deviate toward public areas protected by impact limit lines will be destroyed by the Range Safety Officer, unless a FTS failure occurs (Event #5). Shown previously, the estimated reliability of the FTS is > 0.995 for redundant systems as utilized on the commercial launch vehicles and the probability of FTS failure is $< 5 \times 10^{-3}$. If the

FTS operates properly, all debris is contained inside the ILL and the public risks are essentially the same as result (b.2). As shown, the probability of public exposure near the launch area resulting from these failure events, including FTS failure, is $\sim 3.78 \times 10^{-6}$. The public risks resulting from this sequence of events will be examined in a later section; however, with an exposure probability this low, the resulting (d.1) casualty expectancy (E_c) will be less than 10^{-6} in all but a most unusual circumstance.

Launch vehicle failures occurring after 60 seconds in flight may fail over the broad ocean areas being crossed or during the overflight of Africa (Event #6).

Those which fail over the ocean follow Events #7-#9. The principal difference for failures occurring in this event sequence is that the conditional probability of reaching land is lower (Event #8) and decreases rapidly with time of flight.

The alternative conditional failure probabilities in Event #6 were derived based on the fact that the dwell time while crossing Africa is less than 3 seconds for a Scout launch vehicle which typically thrusts for approximately 215.6 seconds. Hence, the conditional probability for failure during this crossing is 3/215.6 or .0139 and, therefore, 0.9861 of such failures would normally occur over the broad ocean area. This results in a probability of impact in Africa (e.1) of approximately 4.5×10^{-4} and an estimated E_c that is less than 10^{-6}.

d. Launch Vehicle Debris Hazards - The hazards to persons and property are a function of the debris generated by the launch vehicle. Launch vehicle debris hazards vary as a function of destruct action, vehicle failure modes and time in flight of the occurrence.

Debris are normally classified by ballistic coefficient, area, weight and number of pieces per category. Debris characteristics for the proposed Scout commercial launch vehicle are shown in **Table 8**[23] below:

TABLE 8. TYPICAL SCOUT DEBRIS CHARACTERISTICS

Flight Phase	Number Fragments	Lethal Areas (ft.^{2})
Launch Phase	1,420#	5,851*
Overflight Phase	284#	1,000*

* Estimated lethal area

e. Launch Area Public Risk Assessment

(1) The risk of a launch area off-range impact for commercial ELVs (specifically Delta II) is currently being evaluated at the WFF. These studies will aid in the determination of the public risks associated with the proposed commercial launch operations for the Delta II vehicle. The following assessment provides a gross (but conservative) estimate of the public risk for Scout ELV launches from the WFF. The mathematical models necessary to perform a more detailed safety analysis for ELV launches that fail and have a subsequent FTS failure do not exist. RTI has computed several estimates of the worst case risks, however, without sophisticated math models these estimates cannot be fully verified.[23]

(2) An abnormal ELV that does not break up on the flight path has the potential for exposing the public to impact and debris hazards for thousands of miles in any direction should the FTS fail. The probability of public exposure, however, decreases as a function of the square of the range from the launch point. Hence, the probability of impact at 10 miles is 100 times greater than the probability at 100 miles and 10,000 times greater than an impact at 1,000 miles. Therefore, if the probability of impact at 10 miles is 10^{-3}, the probability at 100 miles is 10^{-5} and at 1,000 miles is 10^{-7}.

(3) The population density for the local area surrounding the WFF is shown by **Figure 23**[24]. This figure illustrates the 1988 population centers and densities within 20 miles of the proposed commercial launch site. The maximum population densities are typically between 100 & 1,000 persons per square mile.

The normal risk measure utilized for judging public risk from the launch of space vehicles is called Casualty Expectancy (E_c). This term is the product of the probability of a public exposure from launch vehicle debris and the total public population exposed to the debris hazard. The equation most used is expressed as:

$$E_c = P_i \text{ x } LA \text{ x } P_d$$

where P_i is probability of debris impact in a specific public area, LA is the lethal area of the debris impacting in that public area and P_d is the population density for the exposed area defined. The probability of impact (P_i) in the general public areas near the launch site is approximately $3.78\text{x}10^{-6}$ based on the event tree shown in **Figure 22**.

The Scout launch vehicle poses the largest fragment debris hazard of the current vehicles being launched from the WFF. From the table above, it was shown that a Scout during it's launch phase will produce an estimated 1,420 fragments and a lethal area of approximately 5,851 sq. ft.. As an example of the launch area risks, it is assumed that approximately 1,420 fragments are generated in a Scout accident at an altitude and velocity that produce a fragment hazard area of 3 miles in diameter at a threat range of less than 20 miles.

A typical debris area for an impact at ranges less than 20 miles is shown as an overlay on **Figure 23**[23].

The area of a circle 20 miles in radius is 1,256 sq. miles of which 40% or 502 sq. miles corresponds with the off-range events from **Figure 22**. A Scout debris area of 3 miles in diameter is equal to 7.1 sq. miles. Since the debris can impact in only one 7.1 sq. mile area for any given failure, the average P_i for the region is equal to: $(3.78 \times 10^{-6}) \times (7.1/502) = 5.35 \times 10^{-8}$. A worst case estimate of the casualty expectancy, E_c, can be determined by assuming that all the population in the region is concentrated in one 7.1 square mile debris area. On this basis:

$P_i = 5.35 \times 10^{-8}$ for any debris impact area within 20 miles

LA = 5,851 sq. ft.

P_D max = 1,000 persons/sq. mi.

Therefore, the estimated maximum E_c is approximately 1.12×10^{-8} for any off-range impact in populated areas of this region. An impact in populated areas is very unlikely, however, should it occur, 2 to 5 casualties could occur based on the E_c assumptions above.

(4) Down Range Public Risks - These risks, which are associated with the vehicle IIP being greater than ~ 20 miles and prior to infringing on a downrange landmass, have not been computed for this assessment. Since these risks are so significantly less than either the launch area or downrange overflight risks, their contribution to this assessment is insignificant.

(5) Overflight Hazards - In order to place satellites in orbit from the WFF, the Scout flight trajectory crosses Africa prior to achieving orbital injection velocity (during fourth stage burn). The typical African overflight region for Scout missions is shown in **Figure 24**[23]. The population density for the overflight corridor is on the average less than 50 persons per square mile with brief exposures to densities between 100-300 persons/square mile, as shown.

African overflight azimuths included are typically between 90^0-129^0 (with launch azimuths from 109^0-126^0 being restricted). If the failure rate of the Scout vehicle were uniformly 0.00021 failures per second (historical failure probability of 0.045 divided by 215.6 seconds of burn operation), the debris area assumed to be approximately 750 square feet (based on fourth stage and payload fragments), the population density as stated above (50 persons/square mile) and the dwell time over Africa is ~ 3 seconds, then an estimated E_c can be determined as follows:

$$E_c = Pf \times \text{Dwell Time} \times LA \times Pd$$

$$E_c = 2.1 \times 10^{-4} \times 3 \times 750 \times 50/5280^2$$

$$E_c = 0.847 \times 10^{-6}$$

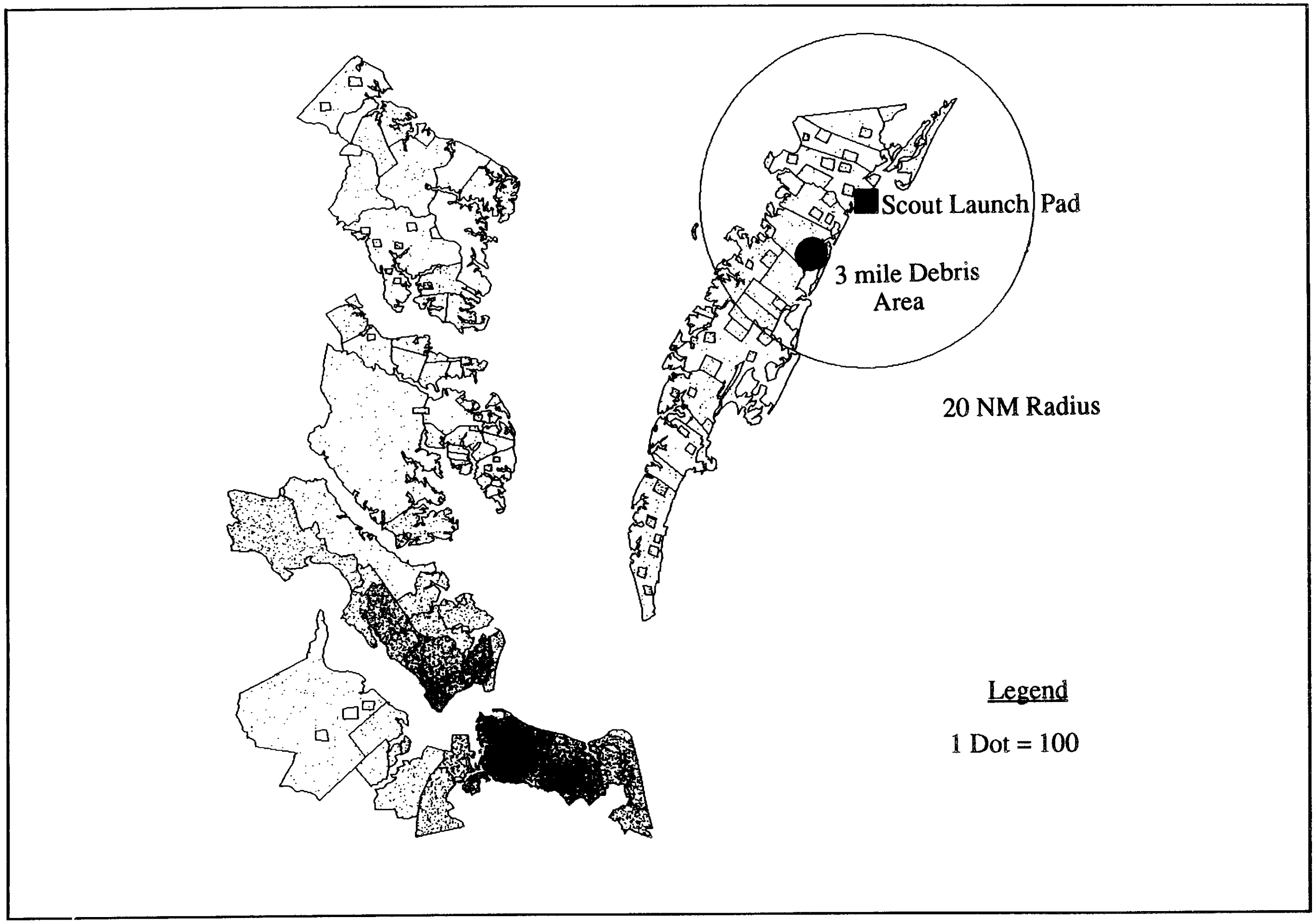


FIGURE 23. RESIDENTIAL POPULATION DENSITY

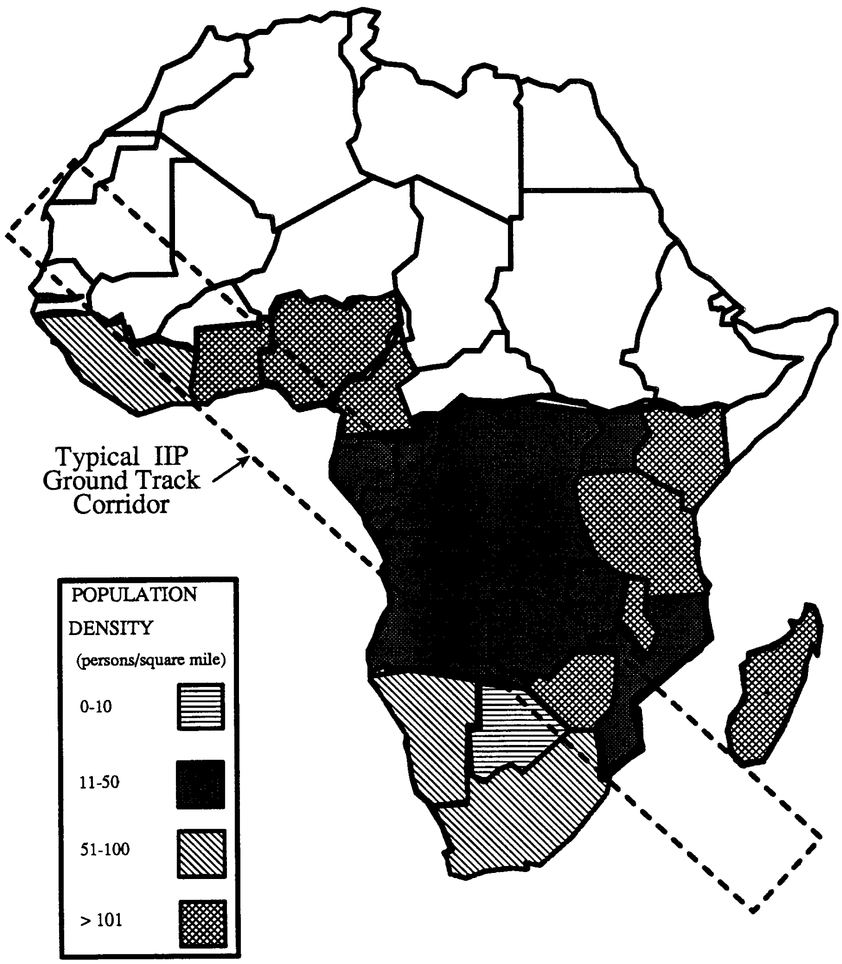


FIGURE 24. AFRICAN OVERFLIGHT CORRIDOR

f. Summary Risks - As shown in this section, the public risks from Scout launches from the WFF are estimated to be approximately one casualty per million launches. More detailed analyses of these risks will typically yield lower estimated public risks. One must be cautious in interpreting these estimates, since the potential for injuries and/or casualties from a single Scout accident can affect numerous persons, although the likelihood of such an occurrence is extremely low.